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(54) **Burnable neutron absorbers.**

(57) A neutron-absorber body for use in burnable poison rods in a nuclear reactor. The body is composed of a matrix of Al_2O_3 containing B_4C, the neutron absorber. Areas of high density polycrystalline Al_2O_3 particles are predominantly encircled by pores in some of which there are B_4C particles. This body is produced by initially spray drying a slurry of Al_2O_3 powder to which a binder has been added. The powder of agglomerated spheres of the Al_2O_3 with the binder are dry mixed with B_4C powder. The mixed powder is formed into a green body by isostatic pressure and the green body is sintered. The sintered body is processed to form the neutron-absorber body. In this case the B_4C particles are separate from the spheres resulting from the spray drying instead of being embedded in the sphere.

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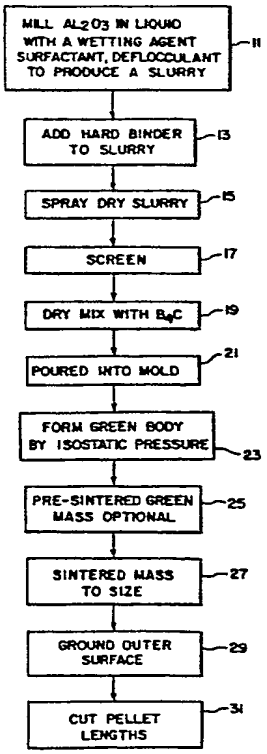

FIG.I.

BURNABLE NEUTRON ABSORBERS

This invention relates to burnable neutron absorbers, also called burnable poisons, for nuclear reactors. The burnable neutron absorbers with which this invention concerns itself are of the type described in United States patent application Serial No. 352,682 (Radford), filed February 26, 1982. Such neutron absorbers include annular ceramic pellets which are stacked in tubes inserted in the core of a reactor. It is with the pellets that this invention concerns itself. Such a pellet includes a matrix of a refractory material which may include aluminum oxide (Al_2O_3) or zirconium oxide ZrO_2 or a combination of the two. A neutron absorber is distributed throughout this matrix. The neutron absorber may include one or more elements or compounds of the metals boron, gadolinium, samarium, cadmium, europium, hafnium, dysprosium and indium. A neutron absorber commonly used is boron carbide (B_4C) either natural or with the boron enriched B^{10}.

In the interest of brevity and concreteness to facilitate the understanding of those skilled in the art in the practice of this invention, this application will deal specifically with a matrix of Al_2O_3 and a neutron absorber of B_4C. It is understood that to the extent that this invention is practiced with other materials, such practice is within the scope of equivalents of this invention as scope of equivalents is defined and described in

the Supreme Court Grover case cited in the Radford application.

The method of producing pellets disclosed in the above-mentioned Radford application and the pellets produced thereby have proven themselves highly satisfactory. However, experience with this method and the pellets produced thereby has led to the conclusion that several improvements are desirable. It is desirable that the pores or voids in the matrix be more efficiently or effectively used to take up the expansion of the B_4C and absorb the helium gas generated by the neutron-boron reaction. It is also desirable that the strength, particularly the compressive strength, of the matrix be improved. It is an object of this invention to provide a method for producing neutron absorbing bodies or ceramics having the above-described desirable properties. It is also an object of this invention to provide a neutron-absorbing body or ceramic having the above desirable properties.

In the procedure of the Radford application, a slurry of a mixture of Al_2O_3 and B_4C powder is spray dried. The resulting dried powder consists of agglomerated spheres of Al_2O_3 in which B_4C particles are embedded. This powder is then pressed into pellets and sintered. It has been realized in arriving at this invention that the invention absorbing effectiveness and the resistance to swelling of the ceramic bodies can be improved and at the same time the strength of the ceramic bodies can be increased by separating the Al_2O_3 and the B_4C in the production of the ceramic bodies.

Accordingly, the present invention resides in a method of making a burnable neutron-absorber for the burnable-poison rods of a nuclear reactor characterized by producing a slurry of a powder of a refractory material including one or more of the class consisting of Al_2O_3 and ZrO_2; adding a binder to said slurry; drying said slurry to produce a powder of agglomerated particles of aluminum oxide including said binder; mixing said powder with a

powder of the class of neutron-absorber materials consisting of one or more elements or compounds of boron, gadolinium, samarium, cadmium, europium, hafnium, dysprosium and indium, to form a mixture of said powders; isostatically compressing said mixture to form a green body; sintering said green body to form a sintered body; and forming said sintered body into a neutron absorber of appropriate shape and dimensions.

In carrying out a method according to one embodiment of the invention, a slurry of the Al_2O_3 alone is produced. A hard binder, typically polyvinyl alcohol, is added and the slurry and binder are spray dried. The product of the spray drying is a powder of agglomerated Al_2O_3 spheres 30 to 50 microns in mean diameter. This powder is mixed with dry B_4C powder 5 to 15 microns in mean size forming a homogeneous mixture. This mixture is pressed isostatically into green tubes which are then sintered. When the mixture is pressed the agglomerates of Al_2O_3 deform and lock together trapping the B_4C particles in the pores. During sintering, the binder volatilizes and the structure of the resulting ceramic has nearly spherical high-density regions of Al_2O_3. These regions are predominantly surrounded by pores and by B_4C particles.

This results in a preferred location in the Al_2O_3 matrix of the B_4C particles and the pores. The matrix of the Al_2O_3 consists microscopically of high density polycrystalline regions and its strength is higher than for the matrix produced in the practice of the invention of the Radford application. Since the Al_2O_3 is dried, the hygroscopic tendency of the matrix is materially reduced. The B_4C particles are predominantly in the pores of the matrix. The available porosity accommodates the swelling of the B_4C particles when bombarded by neutrons and the resulting helium gas.

In order that the invention can be more clearly understood, a convenient embodiment thereof will now be

described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 is a flow chart of a method of making burnable neutron-absorber ceramic pellets;

Fig. 2 is a photomicrograph of a ceramic body produced by the method of Fig. 1; and

Fig. 3 is a photomicrograph of a ceramic body produced in accordance with the method of the above-mentioned Radford application and is presented for comparison purposes.

In the first step 11, a powder of Al_2O_3 is milled in a ball mill in a liquid, typically water which may be deionized. Small but effective quantities of a wetting agent, a surfactant and a deflocculant are added to the water and Al_2O_3. The mean size of the Al_2O_3 is 10 to 30 microns. The relative quantities of the Al_2O_3, the water and the other components are substantially the same as disclosed in the Radford application. The result of the milling is a slurry containing about 40% Al_2O_3 only.

In the second step 13 a hard binder, such as polyvinyl alcohol, is added to the slurry. In the third step 15 the slurry is spray dried in apparatus as disclosed in the Radford application. The spray drying results in spheres of agglomerated particles of Al_2O_3 having a mean diameter of about 30 to 50 microns. In the fourth step 17 this powder is screened to eliminate excessively large agglomerates. In the next step 19 a homogeneous mixture of the Al_2O_3 agglomerates and B_4C powder is produced. The content of the B_4C powder in this mixture in weight percent may be between 1 and 50. The mean size of the B_4C particles is between 5 and 15 microns.

The remaining steps 21 to 31 are the same as the corresponding steps of the Radford application. The homogeneous mixture is poured into a mold, step 21. A green cylinder or green mass is formed by compressing the powder in the mold by isostatic pressure, step 23. Optionally the green cylinder may be presintered, step 25. The mass

is sintered to size, step 27. The sintering is in an atmosphere of argon at about atmospheric pressure and the sintering temperature is between 1400°C and 1800°C. The outer surface of the sintered body is ground, step 29. Ceramic pellets of B_4C in a matrix of Al_2O_3 are cut from the cylinder.

The microstructure of the ceramic body so produced is shown in Fig. 2. As indicated a length of about 1/16 inch on the photomicrograph corresponds to 5 microns. The black areas 33 on the photomicrograph are reproductions of the pores, the dark-gray areas 35 of the B_4C. The regions of Al_2O_3 alone are interlocked as appears at 39. The B_4C regions are in pores surrounding the Al_2O_3 as appears at 41.

The photomicrograph shown in Fig. 3 is presented purely for comparison purposes. This photomicrograph also shows black areas 33 corresponding to pores, dark-gray areas 35 corresponding to Al_2O_3 and light-gray areas 37 corresponding to B_4C. But the interlocked regions of Al_2O_3 alone are absent. Nor is the B_4C in pores encircling the Al_2O_3. The B_4C as shown in Fig. 3 intermingles with the Al_2O_3.

IDENTIFICATION OF REFERENCE NUMERALS USED IN THE DRAWINGS

LEGEND	REF. NO.	FIGURE
MILL Al_2O_3 IN LIQUID WITH A WETTING AGENT SURFACTANT, DEFLOCCULANT TO PRODUCE A SLURRY	11	1
ADD HARD BINDER TO SLURRY	13	1
SPRAY DRY SLURRY	15	1
SCREEN	17	1
DRY MIX WITH B_4C	19	1
POURED INTO MOLD	21	1
FORM GREEN BODY BY ISOSTATIC PRESSURE	23	1
PRE-SINTERED GREEN MASS OPTIONAL	25	1
SINTERED MASS TO SIZE	27	1
GROUND OUTER SURFACE	29	1
CUT PELLET LENGTHS	31	1

CLAIMS:

1. A method of making a burnable neutron-absorber for the burnable-poison rods of a nuclear reactor characterized by producing a slurry of a powder of a refractory material including one or more of the class consisting of Al_2O_3 and ZrO_2; adding a binder to said slurry; drying said slurry to produce a powder of agglomerated particles of aluminum oxide including said binder; mixing said powder with a powder of the class of neutron-absorber materials consisting of one or more elements or compounds of boron, gadolinium, samarium, cadmium, europium, hafnium, dysprosium and indium, to form a mixture of said powders; isostatically compressing said mixture to form a green body; sintering said green body to form a sintered body; and forming said sintered body into a neutron absorber of appropriate shape and dimensions.

2. A method according to claim 1, characterized in that the mean size of the aluminum oxide powder in the slurry is from 10 to 20 microns and the mean size of the powder of the neutron absorber material is from 5 to 15 microns.

3. A method according to claim 1 or 2, characterized in that the slurry is spray dried producing aluminum oxide spheres of 30 to 50 microns mean diameter.

4. A method according to claim 1, 2 or 3 characterized in that the neutron absorber material in the mixture of powders is boron carbide (B_4C) and the content of the B_4C in the mixture in weight percent is from 1 to 50.

5. A method according to any of claims 1 to 4, characterized in that the green body is sintered in an atmosphere of argon at about atmospheric pressure at a temperature of between 1400°C and 1800°C.

6. A method according to any of claims 1 to 5, characterized in that the binder is a hard binder.

7. A burnable neutron absorber body for use in the burnable-poison rods of a nuclear reactor, characterized in that said body is formed of a porous matrix of Al_2O_3, said matrix including high-density polycrystalline particles of Al_2O_3 juxtaposed to pores in which pores there are particles of B_4C.

8. A body according to claim 7, characterized in that the pores substantially encircle the Al_2O_3 particles, said encircling pores partially or wholly containing particles of B_4C.

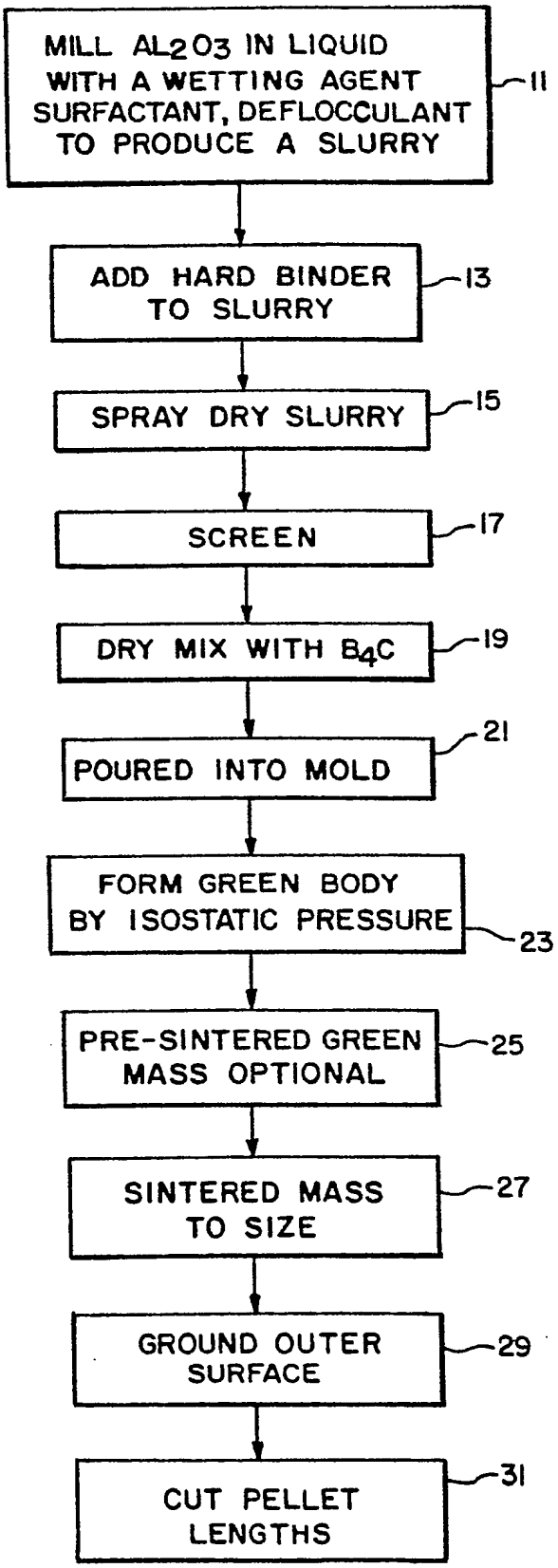

FIG.1.

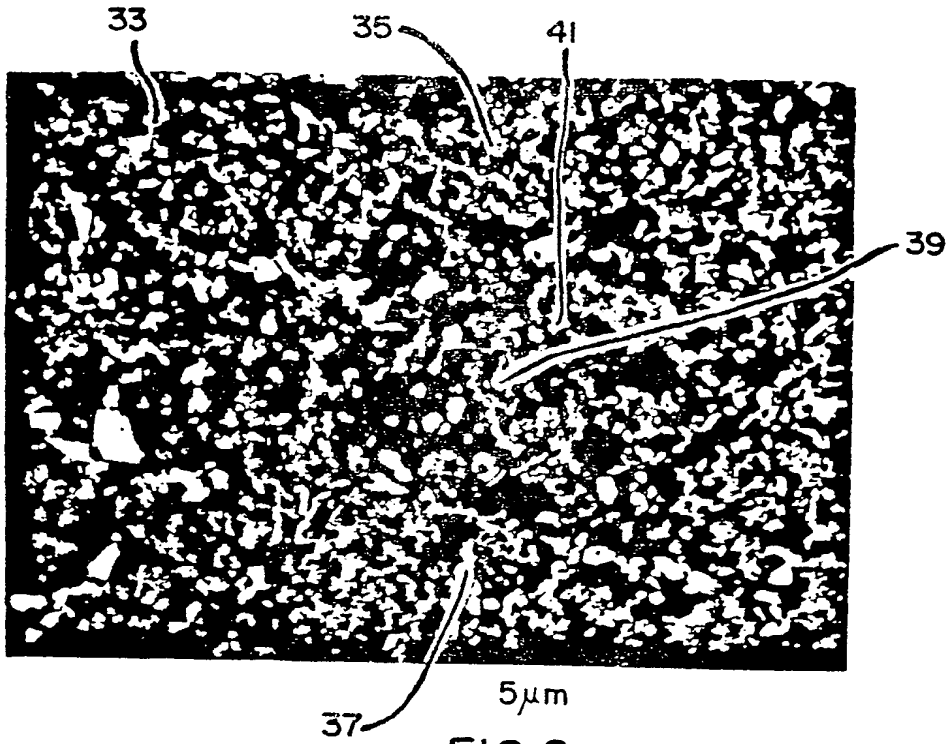

FIG. 2.

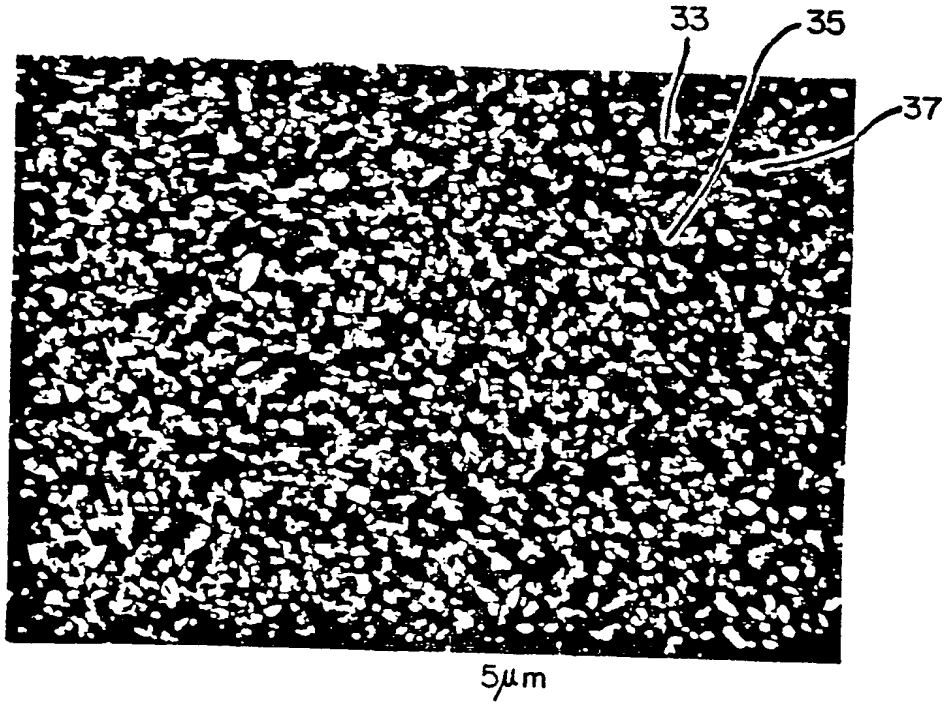

FIG. 3.